Hindawi
Mathematical Problems in Engineering
Volume 2023, Article ID 8118981, 19 pages
https://doi.org/10.1155/2023/8118981

Research Article

Synergistic Agglomeration of Manufacturing and Logistics Industries and Urban Green Economy Efficiency: Influence and Upgrading

Qian Zhang [1] **and Ye Tao** [2]

[1]*School of Humanities, Anhui Polytechnic University, Wuhu 241000, China*
[2]*School of Materials, Anhui Polytechnic University, Wuhu 241000, China*

Correspondence should be addressed to Ye Tao; taoye@mail.ahpu.edu.cn

Received 11 October 2022; Revised 23 October 2022; Accepted 24 November 2022; Published 3 February 2023

Academic Editor: Conghu Liu

Synergistic industrial agglomeration has an impact on green economy. In this research, the evaluation index system of urban green economic efficiency (GEE) is constructed; the superefficiency SBM model, Malmquist index method, location entropy method, and Tobit regression analysis are used to analyse the static and dynamic GEE, the industrial agglomeration level of manufacturing and logistics industries, the synergistic agglomeration level of the two, and the influencing factors of GEE of 41 cities and four provinces in the Yangtze River Delta (YRD) region from 2010 to 2019. The results show that the urban GEE in the YRD region is generally not high, and the annual change trend of efficiency is U-shaped. In the YRD region as a whole and in each province, the relationship between the synergistic agglomeration level of the two industries and the GEE presents regional heterogeneity and GEE is influenced by various factors. Synergistic alignment and integrated development of the two industries are good ways to optimize and upgrade industrial structure transformation. The government can improve urban GEE by adjusting the horizontal and vertical intergovernmental relations as well as adjusting the talent support mechanism to promote integration of technologies with industry and optimizing the upgrading and transformation of industrial structure to achieve sustainable industry development.

1. Introduction

1.1. Research Background. The concept of green economic efficiency (GEE) was first proposed by environmental economist Pearce in 1989 [1]. It mainly refers to the economic development efficiency including the input factor of energy consumption and the output factor of environmental pollution, and it clearly demonstrates the importance of ecological and environmental factors in economic development and transformation. The efficiency of green economy includes two aspects: green efficiency and economic efficiency. By taking environmental pollution factors into account in the undesirable output, the efficiency of sustainable development of economy can be more accurately measured.

In 2019, the State Council of China approved the overall plan for the Yangtze River Delta (YRD) Eco-Green Integrated Development Demonstration Zone, which emphasized the urgency of industrial green transformation in the YRD region. In 2021, the Office for the Steering Group of the YRD region Integrated Development promulgated the YRD Regional Integrated Development Programme for the implementation of the 14th National 5-Year Plan, in which prospects and plans are put forward to strengthen regional coordinated development, promote interprovincial cooperation in linkage agglomeration areas, promote ecological environment construction, and build a green YRD region. Figure 1 shows the overall map of the YRD region. As a region with relatively rapid economic development, better innovation capability, and more mature institutional system

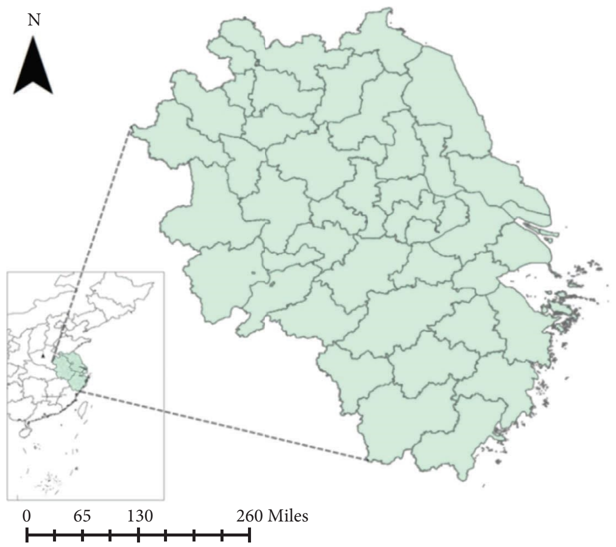


Figure 1: Overall map of the research region.

compared to the national average, the YRD region attracts a large number of inward investment enterprises, and industrial agglomeration becomes one of the core factors to promote regional economic progress. However, industrial aggregation promotes resource and information sharing, reduces production, innovation, and environmental protection costs, but at the same time, it may lead to environmental pollution and hinder sustainable development. With the deepening of the concept of green growth and sustainability to meet the "Double Carbon" (in 2020, the Chinese president pledged at the United Nations General Assembly that China would peak its carbon emissions by 2030 and become carbon neutral by 2060) goal set by Jinping Xi, the President of China, how to adapt such agglomeration in the YRD region to improve GEE has become a concern.

The coordinated development and collaborative production mode of the manufacturing and producer services industries can optimize resource allocation, push the transformation of the manufacturing industry from the traditional extensive development mode to that of green and knowledge-technology intensive growth, and promote the green transformation of the industry and the green economic development of regions [2]. Logistics is an important part of the producer services industry which is closely connected with the manufacturing industry [3]. Since the State Council listed the interactive development of the manufacturing and logistics industries as one of the "Nine Major Projects" in 2009, the two industries have gradually presented a pattern of integrated development, and their synergistic agglomeration has become an important stage in the evolution of future industrial integration and green transformation and upgrading and has become a potential factor that may influence the increase of regional green economic efficiency.

Researching on the status quo of the synergistic agglomeration level of the manufacturing and logistics industries and GEE in the region, exploring the influencing factors of GEE, analyzing the influencing mechanism of the two industries' synergistic agglomeration on GEE, and investigating regional heterogeneity can provide a clear image of the direction of optimizing and upgrading industrial structure transformation by synergistic agglomeration and contribute to the green upgrading of the two industries as well as the sustainable development of the region.

1.2. Literature Review

1.2.1. Studies on the Synergistic Agglomeration of Manufacturing and Logistics Industries. Synergistic industrial agglomeration plays a significant role in promoting industrial integration as well as regional economic development. Collaborative development of the manufacturing and logistics industries is required in order to improve the competitiveness of the manufacturing industry [4], and the synergistic agglomeration of the two industries is the main manifestation of coordinated linkage and integrated development of the two industries [5].

In terms of synergistic agglomeration status, the research findings on the synergistic agglomeration status of the two industries can be summarized from three dimensions: synergistic agglomeration mechanism dimension, time dimension, and space dimension. Specifically, we have (1) studies on the mechanism of collaborative agglomeration between the two industries. Zhan et al. [6], Zhao and Chen [7], and Lu [8] believe that manufacturing and producer services can spur each other, and the agglomeration of manufacturing affects the synergistic amalgamation of the two. Qi [9], Zhou [10], and Yan [3] all demonstrate that the logistics industry is a spin-off from the manufacturing industry, and the coordinated development of the two can save costs, add value, and improve efficiency for the latter. Some scholars also discussed that the degree of agglomeration of different industries within the two industries is different; for example, Zhu et al. studied the agglomeration patterns of the manufacturing and logistics industries and found that the agglomeration level of resource-intensive industries increased significantly [11]. In many of these studies, logistics is regarded as a subindustry of producer services or an industry separate from manufacturing, but studies taking the logistics industry as an independent industry and analysing the mechanism of synergistic agglomeration between logistics and manufacturing industries are limited. (2) The degree of collaborative agglomeration changes with time. For example, Tang et al. studied the collaborative agglomeration level of the two industries in the new land-sea corridor in western China and found that its level declined first and then rebounded, and the collaborative agglomeration level was affected by government intervention, city scale, human capital, economic development, and other factors [12]. (3) The level of collaborative agglomeration in different regions is different; for example, Jin made regional comparisons of the degree of agglomeration of two industries, i.e., manufacturing and producer services, and found that the synergistic level is higher in large and medium-sized cities and economically developed regions [13]. Zhang and

Wu, through empirical analysis, found that the collaborative agglomeration level of the logistics industry and the manufacturing industry in China's provinces showed a spatial evolution pattern of decreasing gradient from east to west [14].

Scholars generally agree that modern industrial integration is not only the amalgamation of labour and geographical location but also the integration of knowledge, resources, technology, and information. The agglomeration status of the two industries presents regional heterogeneity and changes with time, but there is no uniform conclusion on the manifestation form of regional heterogeneity in academia.

In terms of the research method, quantitative analysis is more frequently used. By constructing an input-output index system, researchers use models such as grey correlation, data envelopment, and the location entropy method [15–18] to measure and analyze the correlation between the manufacturing and producer services industries. Most scholars believe that the manufacturing industry plays a strong driving role in the collaborative integration of the two industries, and logistics, now recategorized to be a part of the producer services industry, plays an obvious role in enhancing the value chain.

1.2.2. Studies on GEE. The key point of green economy is that economic development should be coordinated with green development. Economic growth should not be at the cost of the environment, and environmental protection should not be at the cost of economic slowdown. The analysis of GEE in academia is mainly based on empirical research, and the research content can be mainly divided into two aspects:

(1) The construction of the GEE measurement index. Methods used by researchers mainly include entropy weight, factor analysis, and principal component analysis. [19]. The input index analyzed by scholars mainly includes the input of capital, manpower, and energy, and the output index mainly includes the expected economic benefits and unexpected environmental pollution. Table 1 gives an overview of indexes selected by scholars for measuring GEE of regional levels in recent years.

Table 1 shows that scholars are very unified in using regional GDP as the indicator for expected output. For unexpected output, the common indicator is the industrial emissions of "three wastes" or the comprehensive pollution index calculated by the entropy method based on the discharge of industrial wastes. It is a popular practice to integrate multiple inputs including capital, labor, and energy in the process of economic production into the evaluation of GEE. Its advantage is that it can take into account the substitution effect between various factors.

However, most literature focuses on the measurement of GEE at the provincial or industry level in China instead of the city level [27]. Taking the provinces as decision-making units is too macro, thus it is not conducive to capturing micro information. Moreover, as the implementation of the "double carbon" target is accelerated, it is necessary to promote the formation of a new mode of green and low-carbon development, but in existing studies, carbon dioxide emissions are not often included in the unexpected output to measure the GEE from the perspective of cities.

(2) Efficiency measurement method and analysis. As a common method to measure efficiency, the data envelopment analysis method is widely used in the measurement of GEE [29–32]. The DEA method is extensively used to measure the efficiency of technological progress by quantifying the relevant elements of environmental pollution and incorporating them into input indicators. With the improvement of the DEA method, methods to measure the efficiency of green economy have also been developed. Researchers often use the SBM model to measure the GEE by incorporating energy input, capital, and labour input into the input index and adding quantitative indicators related to pollution into the unexpected output index to construct an input-output model [33–37]. Most of the research studies conclude that GEE still needs to be improved and there are regional differences. GEE is influenced by various factors, which mainly include government intervention, human capital, environmental regulation, and technological innovation.

(3) Influencing factors of GEE. Research on the influencing factors of GEE is abundant. Scholars mainly explore the influencing factors from two perspectives. The first is the core influencing factor related to their research studies. For example, Jiang and Jiang [38], Zeng and Xiao [39], and Guan et al. [40] focused on the impact of digital economy on GEE; Zhang et al. [26], Zhou and Gu [22], Li et al. [25], and Roumei and Deng [41] studied the influence of factor resources such as labor force, land, and infrastructure on GEE; Zhang and Tu [24], Zhang and Guo [42], and Ren et al. [43] focused on the influence of industrial agglomeration such as manufacturing and service industries' agglomeration on GEE. The second is the environmental factors. The main content of PEST analysis is that the external environment is mainly composed of four parts: political, economic, social, and technological. Scholars generally select government intervention, economic environment, social development, talent level, and foreign investment environment as macro environmental factors influencing GEE, which is also consistent with PEST theory.

1.2.3. Studies on the Impact of Synergistic Industrial Agglomeration on GEE. Research studies on the relationship between synergistic industry agglomeration and GEE can be divided into three main aspects: first, the agglomeration

Table 1: Selected input and output indexes in the existing articles.

Input indexes	Expected output	Unexpected output	Author and year
Total energy consumption Capital stock Number of employed population	Regional GDP	Total industrial pollution (calculated from the discharge of three industrial wastes using the entropy method)	Wang et al. 2022 [19]
Number of employed population Capital stock Electricity consumption of the whole society	Regional GDP	Total industrial pollution (calculated from the discharge of three industrial wastes using the entropy method)	Cai and Xu, 2022 [20]
Number of employed population Capital stock Power consumption	Regional GDP	Industrial emissions of "three wastes"	Cai et al. 2022 [21]
Construction land area Electricity consumption of the whole society Number of employed population Capital stock	Regional GDP	Industrial emissions of "three wastes"	Zhou and Gu, 2022 [22]
Total energy consumption Capital stock Number of nonagricultural employed population	Regional nonagricultural GDP	Industrial emissions of "three wastes" CO_2 emission	Lin, 2021 [23]
Number of employed population Capital stock Electricity consumption of the whole society	Regional GDP	Industrial emissions of "three wastes"	Zhang and Tu, 2021 [24]
Number of employed population Capital stock Power consumption	Regional GDP	Industrial emissions of "three wastes"	Li et al. 2021 [25]
Number of employed population Capital stock Total energy consumption	Regional GDP	Chemical oxygen deemand SO_2 emission Production of industrial solids	Zhang et al. 2020 [26]
Capital stock Quantity of labour force Total energy consumption	Regional GDP	Industrial emissions of "three wastes"	Lin and Tan, 2019 [27]
Investment in fixed assets Number of employed population Electricity consumption of the whole society	Regional GDP	Concentration index of PM2.5 & PM10 industrial emissions of "three wastes"	Zhu et al. 2018 [28]

provides opportunity for the sharing of all kinds of resources, promotes the formation of scale economies, reduces costs, and improves efficiency of productivity, so it is conducive to economic growth and sustainable utilization of resources. For example, Wu and Yang believe that the synergistic agglomeration of manufacturing and producer services industries can promote the high-quality development of regions and cities [44]. Zhang et al. analyzed the same phenomenon in eastern coastal areas and found that it has a continuous role in driving the regional green economy development [45]. Second, the coordinated industrial agglomeration leads to intensive market transactions, which not only brings pressure to the construction and use of infrastructure but also creates a burden for the environment. For example, Wu argued that in the eastern part of China, the synergistic agglomeration of services and strategic industries inhibited economic growth [46]. Third, there are differences in natural resources and economic development in different regions, so the impact of industrial agglomeration patterns on the environment is different. Also, the relationship between them may be nonlinear. For example, Zhao et al. believe that the aggregation of scientific and technological talents in certain regions has a threshold effect on the impact of industrial synergistic agglomeration on high-quality economic development [47]. Fang et al. believe that such agglomeration needs technological innovation as an intermediary variable to promote sustainable economic development [48]. Ma et al. believe that the agglomeration will inhibit high-quality economic development in the initial stage and that its impact will turn from negative to positive when it reaches a certain threshold [49]. Feng et al. investigated the industrial agglomeration and green development of 285 cities in China and found that the impact of such consolidation on green development was nonlinear and the spillover effect was greater than the direct effect [50]. The academic consensus is that synergistic industrial agglomerations have an impact on green development, and it is vitally important to study the impact in order to promote sustainable development, but there is no unified conclusion on the impact mechanism.

1.2.4. Studies on the Impact of Synergistic Agglomeration of Manufacturing and Logistics Industries on Green Economy Efficiency. There are limited studies on the relationship of the synergistic industrial agglomeration of the two sectoral groups, i.e., manufacturing and logistics, on GEE. Liu studied the impact of the collaborative agglomeration of the two on high-quality economic development [51]. Relevant statements about green and sustainable development are included in his description of high-quality economic development, but he did not explore them in depth. Yan and Wang studied the impact of professional and collaborative agglomeration of the two on regional economic growth and demonstrated that the agglomeration development of the two industries is not only an important means to promote the deep integration of the two, but it is also an important measure to promote economic growth and supply-side structural reform [52]. The synergistic agglomeration of the two industries has a relatively large impact on regional economic growth and a significant positive spillover effect on other regions. However, this research did not discuss the influence of the agglomeration of the two industries on green development either.

The existing studies have laid a solid foundation for improving awareness of the impact of industrial collaborative agglomeration on GEE, building the synergistic relationship between the two industries, constructing the evaluation index system for GEE, and have also provided an important reference for exploring the influencing factors of GEE, as well as selecting the method to calculate GEE. However, there are still problems:

(1) There are many studies on the collaborative agglomeration of manufacturing and producer services, but few studies are on the collaborative agglomeration of logistics and manufacturing. As an important separate component of the manufacturing industry, the logistics industry can return value and embed a new value chain for the former through agglomeration. Therefore, it is necessary to explore the synergistic agglomeration level between the logistics industry and the manufacturing industry and the influence mechanism of this level on sustainable economic efficiency. Also, with the rapid development of the economy, the level of professional and collaborative agglomeration of industries changes rapidly. Putting the research period in recent years is also conducive to observing the spatial and temporal evolution of the collaborative agglomeration level of the two industries.

(2) The decision-making units of the existing studies are mostly provinces in China, and the research results are relatively macroscopic. The spatial differences of economic development in China are remarkable, which are not only reflected in the provinces, but they are also reflected in the regions and cities. Paying attention to the GEE of economic development hotspots (such as the YRD region) is conducive to seeking sustainable development strategies and improving GEE according to local conditions.

(3) With the acceleration of the implementation of the "double carbon" target, green and low-carbon development transition is imminent. However, in the existing studies, carbon dioxide emissions are not often included in the unexpected output to measure urban GEE.

(4) The sharing of resources, information, knowledge, technology, and other elements formed in the collaborative agglomeration of industries may bring agglomeration advantages and promote the green and high-quality development of the economy. However, the collaborative agglomeration of industries may also lead to the waste of resources and the aggravation of pollution, which is not conducive to the improvement of the GEE. At present, there is no unified conclusion on the influence mechanism of industrial collaborative agglomeration on GEE; thus, further research is needed. Also, since the synergistic agglomeration of the logistics and manufacturing industries has a relatively large impact on regional economic growth and since green and sustainable development are important components of high-quality economic growth, it is necessary to explore the relationship between synergistic agglomeration of the manufacturing and logistics industries and green economy efficiency.

In this research, under the guidance of the "double carbon" target, carbon dioxide emissions are included in the unexpected output, and the superefficiency SBM model and Malmquist index model are used to calculate the GEE of 41 cities in the YRD region. Then, the location entropy method is used to calculate the agglomeration level of the manufacturing and logistics industries and the synergistic agglomeration level of the two in 41 cities. Moreover, with the GEE calculated by super-SBM used as the dependent variable, the professional and synergistic agglomeration level of the manufacturing and logistics industries used as the core independent variable, and other environmental factors used as control variables, the Tobit model is used to calculate the influencing factors of urban GEE of the region. Finally, based on the empirical analysis, corresponding policy suggestions are put forward. The research framework is shown in Figure 2. The contribution of this research is mainly in three aspects:

(1) Theoretically, taking the collaborative agglomeration of manufacturing and logistics industries as the breakthrough point, this research jumps out of the discussion paradigm of "collaborative agglomeration of producer services and manufacturing industries" as the independent variables in the existing research. The research object is more focused, which enriches the perspective and content of the research on industrial collaborative agglomeration to promote GEE. Also, responding to the call of energy saving and carbon reduction policies, CO_2 emission is included in the unexpected output index used to evaluate urban GEE, and by doing this, the evaluation index model of urban GEE can be enriched.

(2) Methodologically, on the one hand, the static and dynamic GEE and its influencing factors of 41 cities are calculated through the consistent use of the SBM–Malmquist–Tobit model methods. It is of innovative and practical significance since the professional agglomeration of the manufacturing and logistics industries and the collaborative agglomeration of the two industries measured by the location entropy method are taken as explanatory variables so as to discuss their influences on the GEE. On the other hand, ArcGIS geographic information system software is used to draw a colored map of the industrial agglomeration level of 41 cities in the YRD region, which directly reflects the industrial agglomeration level, and lays a foundation for deducing the influence of the industrial collaborative agglomeration level on GEE.

(3) Practically, the discussion of this research is of practical value for optimizing the green transformation of industrial structure and agglomeration and is of practical significance to local governments in the YRD region and the central government of China to formulate corresponding policies to guide the route of industry transformation, technology progress, and thus the development of green economy.

2. Materials and Methods

2.1. Model Construction

2.1.1. Superefficiency SBM Model. The radial data envelopment analysis method (DEA), first proposed by Charnes et al. [53], has been widely used in the academic field. This method is suitable for measuring the efficiency of multiple DMUs (decision-making units) with the same input and output indexes. However, this method cannot consider the possible effects of undesired output and slack variables. Tone [54] proposed the SBM model that can avoid the abovementioned problems when calculating, but it is easy to have multiple DMUs with effective measurement results, which is not conducive to the efficiency comparison. Therefore, he improved the model and proposed the superefficiency SBM model. In this research, the nonoriented superefficiency SBM model is selected, and its basic expression is as follows:

$$\min \rho^* = \frac{1/m \sum_{i=1}^{m} x^{'}/x_{ik}}{1/r + p\left(\sum_{s=1}^{r} y^d y_{sk}^d + \sum_{q=1}^{r_2} y^u y_{qk}^u\right)},$$

$$s.t.\begin{cases} x^{'} \geq \sum\limits_{j=1,\neq k}^{n} x_{ij}\lambda_j; \\ y^d \leq \sum\limits_{j=1,\neq k}^{n} y_{sj}^d\lambda_j; \\ y^d \geq \sum\limits_{j=1,\neq k}^{n} y_{qj}^d\lambda_j, \\ x^{'} \geq xk; \\ y^d \leq y_d^k; \\ y^u \geq y_k^u, \\ \lambda_j \geq 0, i = 1, 2, \cdots, m; \ j = 1, 2, \cdots, n, \ j \neq 0, \\ s = 1, 2, \cdots, r; q = 1, 2, \cdots, p. \end{cases} \tag{1}$$

In equation (1), ρ^* represents the GEE value of 41 cities in the YRD region, n represents the number of DMUs, i.e., 41 cities, m represents the number of input indicators, r and p represent the number of expected and unexpected output indicators, x is the element of the corresponding input matrix, y^d and y^u represent the elements of the corresponding expected and unexpected output matrices, and λ is the weight vector. When $\rho^* \geq 1$, it means that the GEE of the city or region is effective and when $\rho^* < 1$, it means that the green economy input of the city or region does not bring the expected output.

2.1.2. Malmquist Index Model. In order to explore the dynamic efficiency changes of GEE of cities in the YRD region, this research uses the Malmquist index model to calculate the annual and regional changes. This index is mainly composed of technical efficiency (effch) and technological progress efficiency (techch), among which technical efficiency can be decomposed into pure technical efficiency (pech) and scale efficiency (sech). Using this index, the total factor productivity of green economy (tfpch) of cities in the YRD region can be measured. The following formulas give the mathematical expression of the Malmquist index model:

$$\text{tfpch} = \text{effch} \times \text{techch} = (\text{pech} \times \text{sech}) \times \text{techch}. \tag{2}$$

Total factor productivity values greater than 1, equal to 1, and less than 1 indicate the GEE improvement, unchanged, and decline, respectively.

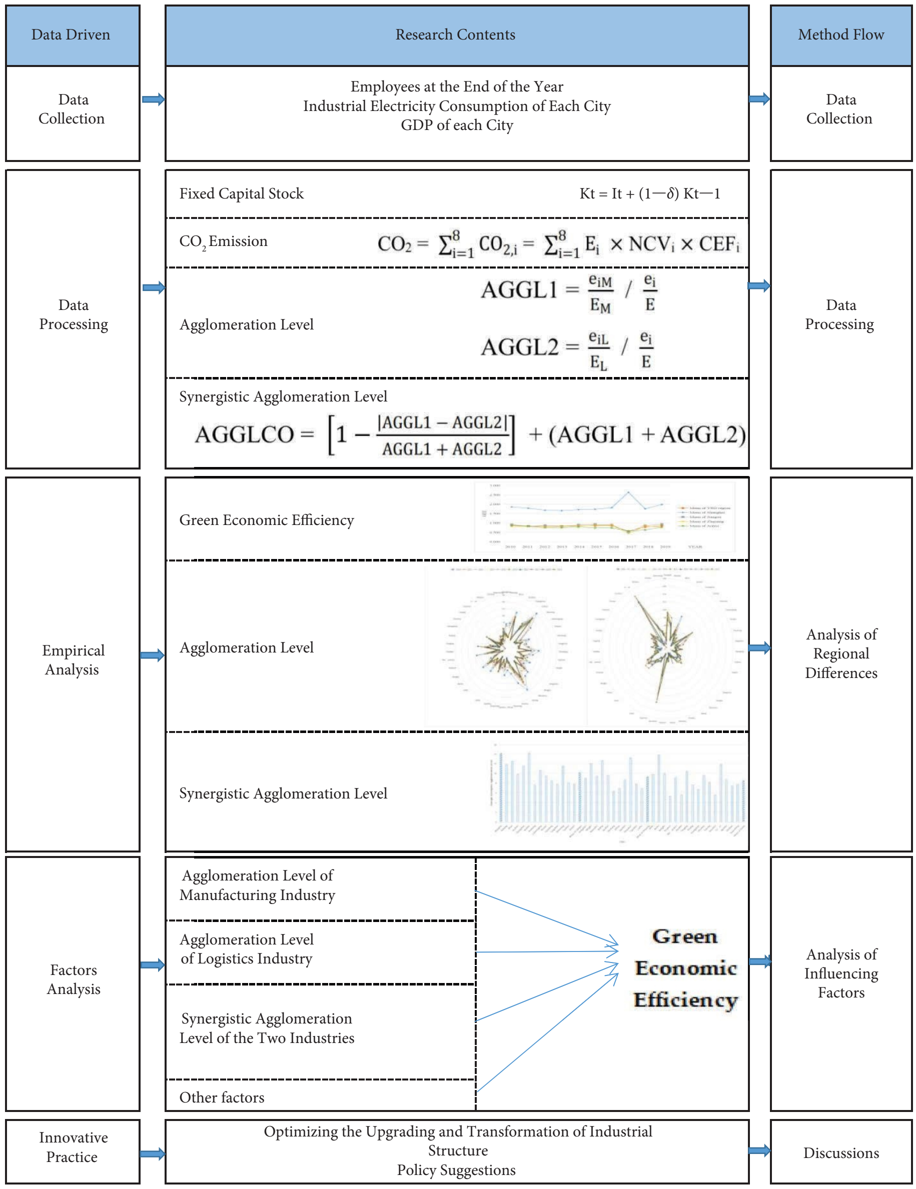


Figure 2: Research process.

2.1.3. Location Entropy Method. Methods that are frequently used to measure the level of industrial agglomeration mainly include the location entropy method, Herfindahl–Hirschman index, DO index, EG index, and space Gini coefficient. This research draws on the practice of Chen and Chen [55] and uses the location entropy method to, respectively, measure the agglomeration level of the manufacturing and logistics industries, as well as the synergistic agglomeration level of the two industries. The specific model is

$$\text{AGGL1} = \frac{e_{iM}/E_M}{e_i/E},$$
$$\text{AGGL2} = \frac{e_{iL}/e_i}{E_L/E}. \quad (3)$$

AGGL1 and AGGL2 represent the agglomeration level of manufacturing industry and logistics industry, respectively. e_{iM} and e_{iL} represent the number of employees of the two industries of each city in each year, respectively, and E_M and E_L represent the number of corresponding employees in China in each year, respectively. e_i represents the number of employees in all industries of each city in each year. E represents the number of employees in all industries of China in each year. With reference to Meng et al. [2], a calculation model for synergistic agglomeration of the two industries is constructed as follows, in which AGGLCO represents the synergistic agglomeration level of the two industries, and AGGL1 and AGGL2 are the professional agglomeration levels calculated in equation (3).

$$\mathrm{AGGLCO} = \left[1 - \frac{|\mathrm{AGGL1} - \mathrm{AGGL2}|}{\mathrm{AGGL1} + \mathrm{AGGL2}}\right] + (\mathrm{AGGL1} + \mathrm{AGGL2}). \tag{4}$$

2.1.4. Tobit Regression. The Tobit model was proposed by Tobin in 1958 [56], which is mainly applied to regression analysis where the value of explained variables is restricted or truncated. In order to avoid the possible estimation bias caused by the ordinary least squares method, this research adopts the random effects panel Tobit model to measure the influencing factors of the GEE of cities in the YRD region. The expression of the Tobit regression model is

$$\begin{aligned} Y_{\mathrm{it}} &= \alpha + \beta X_{\mathrm{it}} + \mu_{\mathrm{it}}, \\ Y_{\mathrm{it}} &= \begin{cases} 0, & Y_{\mathrm{it}} \leq 0, \\ Y_{\mathrm{it}}, & Y_{\mathrm{it}} > 0. \end{cases} \end{aligned} \tag{5}$$

In equation (5), i represents city, t represents year, Y_{it} is the GEE value of the i^{th} city in the year t calculated using the superefficiency SBM model, X_{it} represents each explanatory variable, α is the constant term, β is the regression coefficient vector, and μ is the random interference term.

2.2. Index Selection and Data Sources

2.2.1. Evaluation Index of GEE. The choice of input and output indicators should take into account not only the availability of data but also the objective needs of evaluation. According to Douglas production function, labour and capital inputs are the basic elements of input factors. Therefore, capital input is expressed by fixed capital stock of each city, and labour input is expressed by employees at the end of each year. Among them, the fixed capital stock cannot be directly obtained from the statistical data; thus, the perpetual inventory method is used to estimate the fixed capital stock over the past years. The calculation formula of capital stock is

$$K_t = I_t + (1 - \delta)K_{t-1}, \tag{6}$$

where K_t represents the capital stock in year t, K_{t-1} represents the capital stock in year $t-1$, I_t represents the investment in year t, and δ represents the depreciation rate in year t. We refer to the research of Zhang et al. [57], $\delta = 9.6\%$ and $I_t = I_0/(\delta + g)$. I_0 represents the investment in fixed assets in 2010, and g is the aggregate average growth rate of new fixed assets in the whole society. In addition, considering the availability of data and with reference to Wu and Wu [58], the industrial electricity consumption of each city is used to represent the energy input. The GDP of each city is selected as the expected output to reflect the development level. The comprehensive pollution index and CO_2 emission of each city are selected as the undesirable output to reflect the environmental pollution status. Among them, industrial wastewater discharge, industrial sulfur dioxide emission, and general industrial solid waste production are selected as the basic indicators, and the entropy value method is used to calculate the comprehensive pollution index of three main industrial wastes in each city. The relevant data mentioned previously are collected from China Urban Statistical Yearbook. The calculation of CO_2 emission includes three aspects: combustion consumption of various energy sources, average low calorific value of various energy sources, and carbon dioxide emission factors of various energy sources. The calculation method is as follows:

$$\mathrm{CO}_2 = \sum_{i=1}^{8} \mathrm{CO}_{2,i} = \sum_{i=1}^{8} E_i \times \mathrm{NCV}_i \times \mathrm{CEF}_i. \tag{7}$$

In equation (6), E_i represents the consumption of each energy ("Each energy" includes coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas. Their NCV values (kJ /kg) are 20908, 28435, 41816, 43070, 43070, 42652, 41816, and 38931, respectively. Their CEF values (kg/TJ) are 95977, 105966, 73333, 71500, 74067, 77367, and 56100, respectively. Data are obtained from IPCC (United Nations Intergovernmental Panel on Climate Change) (2016)), NCV_i represents the average low calorific value of each energy, and CEF_i represents the CO_2 emission factor of each energy. Relevant data are collected from China Energy Statistical Yearbook, China Industrial Statistical Yearbook, and China Environment Statistical Yearbook, the method can be used to calculate the overall CO_2 emissions of provinces in China, and then referring to the estimation method used by Ding et al. [59], the ratio of urban GDP to provincial GDP is used to estimate CO_2 emissions for each city. The evaluation index of GEE is shown in Table 2.

2.2.2. Influencing Factor Index Selection. The efficiency value of urban green economy measured by the superefficiency SBM model is used as the dependent variable, and the agglomeration levels of the manufacturing industry (AGGL1) and the logistics industry (AGGL2), as well as the synergistic agglomeration levels of the two industries calculated by the location entropy method, are taken as the core independent variables (AGGLCO). Combined with political, economic, and social factors, the control variables of external influencing factors are selected as follows:

(1) Government Intervention (GOV). Government intervention is an important means for the government to carry out macrocontrol, aiming to promote the effective operation of the economy and the positive development of the industry. The typical method of regulation and control is fiscal expenditure, which is represented by the general public budget expenditure of each city; (2) social development level (SOCIAL): the urbanization rate is one of the important indicators of Chinese urban social development, which is represented by the ratio of the permanent urban resident population to the total urban resident population including nonpermanent city dwellers such as people living in rural places and migrant workers at the end of the year; (3) industrial structure (INSTRU): represented by the ratio of the output value of the secondary industry to the local GDP to reflect the industrial structure relationship of the city; (4)

Table 2: Evaluation index of GEE.

Types	Measure dimension	Measure index	Symbol
Input	Financial capital	Fixed capital stock	$X1$
	Labour capital	Employees at the end of the year	$X2$
	Energy	Industrial electricity consumption of each city	$X3$
Output	Expected output	GDP of each city	$Y1$
	Unexpected output	Comprehensive pollution index of three main industrial wastes	$Z1$
		CO_2 emission	$Z2$

human resource level (EDU): the professional and comprehensive ability of human resources may have a crucial impact on industrial upgrading and transformation and urban green development, and this is represented by the number of university students per 10,000 people; (5) opening to the outside world (FOREIGN): the opening to the outside world can reflect the overall development level of a city, and this is represented by the actual amount of foreign investment in each year (Table 3). The missing data have been interpolated by using the equivalent mean imputation method. The construction model is as follows:

$$\begin{aligned}\text{GEE}_{\text{it}} &= C + \alpha_1\text{AGGL1}_{\text{it}} + \alpha_2\text{AGGL2}_{\text{it}} + \alpha_3\text{AGGLCO}_{\text{it}} \\ &\quad + \alpha_4\text{InGOV}_{\text{it}} + \alpha_5\text{SOCIAL}_{\text{it}} + \alpha_6\text{INSTRU}_{\text{it}} \\ &\quad + \alpha_7\text{InEDU}_{\text{it}} + \alpha_8\text{InFOREIGN}_{\text{it}} + \varepsilon_{\text{it}}.\end{aligned} \tag{8}$$

Of which, GEE_{it} represents the urban green economy efficiency value of the i^{th} city in the t year measured by the superefficiency SBM model, C is the intercept term,$\alpha 1$–$\alpha 8$ are regression coefficients of explanatory variables, and ε_{it} is the random error term. The units of general public budget expenditure of each city have been converted to US dollars at the latest exchange rate. To avoid heteroscedasticity, logarithms of the general public budget expenditure of each city, the actual amount of foreign investment, and the number of university students per 10,000 people were taken.

3. Results

3.1. Static Analysis. Data are imported into MATLAB software, and the superefficiency SBM model containing undesired output is used to calculate the GEE of 41 cities in the YRD region. The research period is from 2010 to 2019. The results are as follows.

3.1.1. Current Status of GEE. In order to compare the GEE of 41 cities (with Shanghai municipality taken as a city) and four provinces (with Shanghai municipality taken as a province) in the YRD region, the efficiency values of 41 cities and four provinces are calculated, respectively (Table 4).

From the perspective of 41 cities, from 2010 to 2019, the average GEEs of Shanghai, Suzhou, and Wuxi in Jiangsu Province and Huangshan, Chizhou, and Bozhou in Anhui Province are greater than 1, indicating that the GEE of these six cities has been effective and the ecological environment and economy have developed in harmony. Among them, during 2016–2019, Suzhou's carbon emissions per ten thousand yuan GDP decreased by 23.3%; since Wuxi City took the lead in establishing an international ecological urban agglomeration in 2013, it has been adhering to the green economic development path of ecological priority and also to the green development concept and therefore has become one of the first demonstration cities of ecological civilization construction in China; Huangshan City is located at the foot of Huangshan Mountain, a world cultural and natural heritage, and Chizhou City has the national 5A Jiuhua Mountain scenic spot, thus thanks to the advantaged natural resources and tourism city development strategy, these two cities have better green economic development ability; Bozhou City has greatly increased forestation since 2013, and the forest coverage rate has repeatedly set new highs.

However, the average GEEs of other cities are lower than 1, among which 22 cities have an efficiency value lower than 0.8, and 5 cities are between 0.3 and 0.6, indicating that the overall GEE of the YRD region is less than satisfactory. From the perspective of the four provinces, the average GEE of Jiangsu, Zhejiang, and Anhui is lower than 1, and the ranking in this respect is Shanghai > Jiangsu > Zhejiang > Anhui. Shanghai's economic development level is higher, the technological innovation ability is good, and the traditional extensive production pattern is gradually transforming to an intensive pattern. Owing to its high-end talent pool and more advanced industrial base, Shanghai has increased digital empowerment in industry transformation and has gradually built a modern industrial system and infrastructure, providing a more favourable condition for promoting green development. The average efficiency of Anhui Province however is lagging behind. The first reason may be that the dependence on traditional manufacturing leads to a long transformation cycle; the second reason perhaps is that resource-based cities such as Huainan are facing the dilemma of resource exhaustion, and the past economic growth is at the cost of the environment resulting in resource depletion, which is difficult to make up in a short term.

3.1.2. Time Evolution of GEE. Figure 3 shows the time evolution of the GEE of the four provinces from 2010 to 2019. Overall, the GEE shows a U-shaped change, and the efficiency values between Shanghai and the other three provinces show obvious differences. From 2010 to 2016, the overall GEE did not fluctuate much. In 2016–2017, the efficiency of Shanghai achieved a significant increase, but all the other provinces saw a decline, and the overall GEE of the four provinces and the YRD region was on a downward

Table 3: Influencing factors of the index system.

Types	Measure dimensions	Measure indexes	Symbols
Core explanatory variable	Industrial agglomeration level	Agglomeration level of the manufacturing industry	AGGL1
		Agglomeration level of the logistics industry	AGGL2
		Synergistic agglomeration level of manufacturing and logistics industries	AGGLCO
Other explanatory variable	Government intervention	General public budget expenditure of each city	*In*GOV
	Social development level	Urbanization rate	SOCIAL
	Industrial structure	Ratio of the output value of the secondary industry to local GDP	INSTRU
	Opening to the outside world	Actual amount of foreign investment	*In*FOREIGN
	Human resource level	Number of university students per 10,000 people	*In*EDU

Table 4: Annual mean value and ranking of GEE of 41 cities in the YRD region in 2010–2019.

City (year)	2010	2019	Annual mean	Rank
Shanghai	1.8600	1.9836	1.8633	1
Nanjing	0.6423	1.0762	0.8009	19
Wuxi	1.0046	1.2195	1.0611	5
Xuzhou	0.7387	1.0655	0.7287	24
Changzhou	1.0610	1.0460	0.9689	10
Suzhou	1.4385	0.8170	1.0849	4
Nantong	0.9320	0.7776	0.8591	15
Lianyungang	0.6701	0.7333	0.6254	34
Huaian	0.5499	1.0361	0.6808	31
Yancheng	1.0688	1.0000	0.9722	9
Yangzhou	1.0000	0.9564	0.8704	14
Zhenjiang	0.8384	1.0325	0.8893	13
Taizhou	1.0533	0.6806	0.8523	16
Suqian	0.9413	0.7145	0.6892	29
Hangzhou	0.6424	0.7473	0.7282	25
Ningbo	0.7928	1.0998	0.8325	18
Wenzhou	1.0000	0.7716	0.9066	11
Jiaxing	0.5750	0.6416	0.6049	36
Huzhou	0.5662	0.6202	0.5790	37
Shaoxing	1.0258	0.6134	0.7289	23
Jinhua	1.0260	0.7092	0.9051	12
Quzhou	0.6504	0.6011	0.5513	38
Zhoushan	0.6449	1.0081	0.9981	7
Taizhou	1.0000	0.7251	0.8428	17
Lishui	1.0000	1.0258	0.9833	8
Hefei	0.7944	1.0267	0.7668	21
Wuhu	0.6643	0.6659	0.6126	35
Bengbu	0.5902	1.0481	0.7037	28
Huainan	0.4041	0.5514	0.4490	41
Ma’anshan	0.6896	0.4983	0.5094	40
Huaibei	0.5364	0.6178	0.5327	39
Tongling	1.0909	0.4725	0.7159	27
Anqing	1.0000	0.7329	0.7163	26
Huangshan	1.1771	1.2830	1.2179	2
Chuzhou	0.9381	0.8067	0.7513	22
Fuyang	0.6434	0.7232	0.7955	20
Suzhou	0.5913	0.7537	0.6552	32
Lu’an	1.0003	0.4815	0.6854	30
Bozhou	1.5088	1.0639	1.0460	6
Chizhou	1.0624	1.0766	1.1064	3
Xuancheng	1.1085	0.5962	0.6322	33
Mean of Shanghai	—	—	1.8633	—
Mean of Jiangsu	—	—	0.8526	—
Mean of Zhejiang	—	—	0.7874	—
Mean of Anhui	—	—	0.7435	—

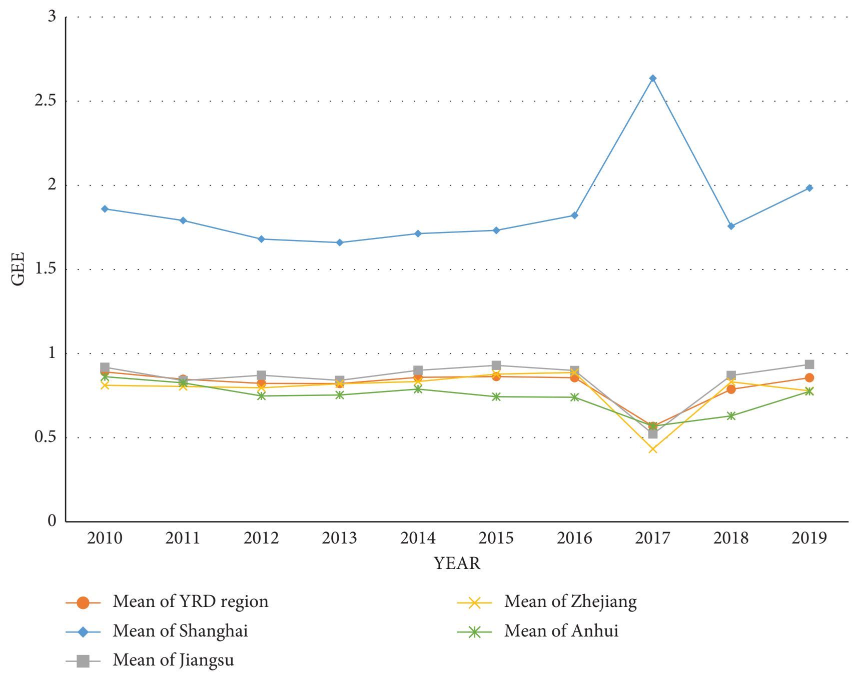


FIGURE 3: Average GEE of four provinces and the whole YRD region in 2010–2019.

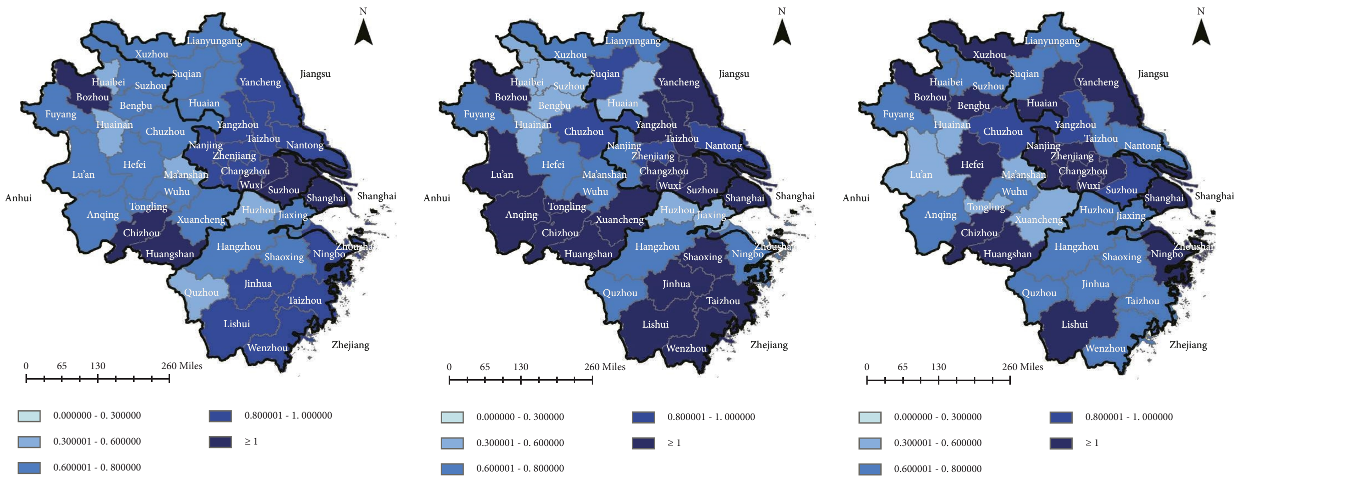
trajectory. From 2017 to 2018, the green economic efficiency of Jiangsu, Zhejiang, and Anhui provinces and the YRD region as a whole saw an upward trend, but that of Shanghai showed a pullback. Then in 2018–2019, slight increase can be seen for Shanghai, Jiangsu, Anhui, and the whole YRD region.

3.1.3. Spatial Evolution of GEE. In 2010, the number of cities with effective green economy in the YRD region was 19, and the number reduced to 16 in 2019. During the research period, the GEE of cities changed significantly. From the perspective of the mean value during 2010–2019, effective cities are mainly located in Shanghai, Jiangsu, and Anhui; in 2010, the effective cities generally showed an average distribution in four provinces, while in 2019, the effective cities were mainly concentrated in Shanghai and in cities of Jiangsu Province (Figure 4). In 2010, 7 cities had an efficiency value below 0.6, while in 2019, the number decreased to 5. It can be seen that the number of cities in the medium and the low efficiency level in 2019 decreased compared with that of 2010.

3.2. Dynamic Analysis

3.2.1. On the Yearly Basis. In order to measure the change of urban GEE in the YRD region, this research uses DEAP 2.1 software to measure the Malmquist index of 41 cities and its decomposition. The results are shown in Table 5. From 2010 to 2019, except for the mean value of technological progress efficiency, all the average values of the index were less than 1, indicating that the GEE of cities in the YRD region showed an overall downward trend, and the average annual total factor productivity declined by 1.5%, which was not a significant drop. The average value of the index of technological progress efficiency was 1.005. From 2010 to 2017, it showed an overall upward trend except for a slight decline from 2013 to 2014. Driven by the improvement of technological progress efficiency, the value of GEE from 2010 to 2017 was also mostly greater than 1. From 2017 to 2019, the efficiency of technological progress fell sharply, leading to a synchronous decline in the GEE. It can be seen that technological progress is the most important factor affecting the urban GEE in the YRD region. Both scale efficiency and pure technical efficiency underwent fluctuating changes but showed no significant impact on the overall efficiency.

3.2.2. Based on Location. From 2010 to 2019, the average Malmquist index of GEE in Shanghai, Jiangsu, Zhejiang, and Anhui was 1.083, 0.982, 0.982, and 0.992, respectively. Among the four provinces, only Shanghai achieved an efficiency improvement of 8.3%. In terms of index decomposition, the technological progress indexes of Shanghai, Jiangsu, and Zhejiang were all greater than or equal to 1. Among them, the technological progress efficiency of Shanghai increased by 15.1%, which greatly promoted the improvement of regional GEE. This further indicates that technological progress is the biggest factor influencing the improvement of urban GEE in the YRD region. The scale efficiency of four provinces was less than 1, indicating that the efficiency of resource utilization needs to be improved (Table 6).



(a) (b) (c)

Figure 4: (a) The color map of the mean efficiency; (b) the color map of efficiency in 2010; (c) the color map of efficiency in 2019.

Table 5: Annual change of green economic efficiency in the YRD region in 2010–2019.

Years	effch	techch	pech	sech	tfpch
2010-2011	0.852	1.104	0.961	0.886	0.941
2011-2012	1.007	1.017	1.011	0.996	1.024
2012-2013	1.018	1.018	1.004	1.014	1.036
2013-2014	1.127	0.918	1.041	1.083	1.034
2014-2015	0.915	1.150	0.973	0.94	1.052
2015-2016	0.979	1.125	0.984	0.995	1.102
2016-2017	0.917	1.272	0.983	0.933	1.166
2017-2018	1.063	0.608	1.018	1.044	0.646
2018-2019	0.972	0.996	1.003	0.969	0.968
Mean	0.98	1.005	0.997	0.983	0.985

3.3. Industrial Agglomeration Level and Level of Industrial Synergy Agglomeration

3.3.1. Agglomeration Level of the Manufacturing Industry and the Logistics Industry. The location entropy method is used to calculate the industrial agglomeration level. The larger the resulting value, the higher the agglomeration level. It can be seen from Figure 5 that, on the whole, the manufacturing agglomeration level in Jiangsu Province is the highest, followed by Zhejiang, Shanghai, and Anhui. The agglomeration level of logistics industry in Shanghai is the highest, followed by Anhui and Jiangsu Provinces, and Zhejiang Province is the lowest in general. In terms of agglomeration trend, the manufacturing industry showed an initial trend of decline before rising slowly, while the improvement of the logistics industry was of a more volatile nature. At the city level, Wuxi, Suzhou, and Jiaxing have the highest level of manufacturing agglomeration, while Huainan, Huaibei, Huangshan, and Suzhou have the lowest. Shanghai, Zhoushan, and Lu'an have the highest agglomeration level of the logistics industry, while Nantong, Suqian, Shaoxing, and Taizhou have the lowest. Cities with a high level of manufacturing agglomeration are mainly located in Jiangsu and Zhejiang, while cities with a low level are mainly in Anhui. The agglomeration level of the logistics industry in each city is not uniform (Figure 6).

3.3.2. Synergistic Agglomeration Level of the Manufacturing and Logistics Industries. In general, Shanghai has the highest level of synergistic agglomeration, followed by Jiangsu and Zhejiang, and Anhui has the lowest level (Figure 7). In terms of city scope, in addition to Shanghai, cities with a high level of synergistic agglomeration also include Suzhou, Jiaxing, Zhoushan, Wuhu, and Lu'an. These cities, especially Shanghai, Suzhou, Jiaxing, and Wuhu, have played a very positive role in driving the level of synergistic agglomeration of their surrounding cities. However, it can be seen from the analysis that the agglomeration level of a single industry is not necessarily high in cities with a high level of industrial synergistic agglomeration (ISA level).

3.4. Influencing Factors. Using EViews 8 software, the Tobit regression analysis method is used to calculate the relationship between the ISA level, other environmental factors, and GEE in the YRD region and its four provinces. The results can be seen in Table 7.

3.4.1. Influence of Industry Agglomeration and Synergistic Agglomeration. From the perspective of the whole YRD region, the coefficients of manufacturing industry agglomeration and logistics industry agglomeration and the ISA level of the two are all positive, and among them, the *P* value of collaborative agglomeration is significant at the 1% level ($P < 0.01$). This indicates that with the increase of the ISA level of the manufacturing and logistics industries in the YRD region, the GEE increased significantly.

From the perspective of four provinces, firstly, the situation of Anhui is consistent with that of the whole YRD region. Both the agglomeration levels of the two industries in Shanghai have a significant positive effect on GEE, whereas the synergistic agglomeration of the two industries has a

Table 6: Regional change of green economic efficiency in the YRD region in 2010–2019.

Cities	effch	techch	pech	sech	tfpch
Shanghai	0.941	1.151	1	0.941	1.083
Nanjing	0.971	1.014	0.997	0.974	0.985
Wuxi	0.981	0.977	0.982	0.999	0.958
Xuzhou	1.004	0.983	1.022	0.983	0.987
Changzhou	0.986	1.003	0.99	0.996	0.989
Suzhou	0.989	0.984	0.993	0.997	0.973
Nantong	0.997	0.996	1.016	0.981	0.993
Lianyungang	0.973	0.968	0.997	0.975	0.941
Huaian	0.979	0.997	0.997	0.983	0.977
Yancheng	0.959	0.977	0.997	0.962	0.937
Yangzhou	1.013	1.003	1.025	0.989	1.017
Zhenjiang	0.995	0.98	1.024	0.972	0.975
Taizhou	0.992	0.99	1.013	0.979	0.981
Suqian	0.98	0.974	1.001	0.979	0.955
Hangzhou	0.925	1.091	1	0.925	1.009
Ningbo	0.943	1.044	0.987	0.955	0.984
Wenzhou	0.953	1.087	1	0.953	1.035
Jiaxing	0.951	0.98	0.981	0.969	0.933
Huzhou	0.966	0.976	0.986	0.98	0.943
Shaoxing	0.944	1.027	0.98	0.963	0.97
Jinhua	0.938	0.967	0.967	0.97	0.907
Quzhou	0.996	0.972	1.001	0.995	0.968
Zhoushan	1.037	1.099	1.037	1	1.14
Taizhou	0.934	1.057	0.973	0.96	0.987
Lishui	0.952	0.972	0.955	0.996	0.925
Hefei	0.994	0.978	1	0.994	0.972
Wuhu	1.004	0.986	1.021	0.983	0.99
Bengbu	1.032	0.989	1.035	0.997	1.021
Huainan	0.968	1.032	0.97	0.998	0.999
Ma'anshan	1.054	0.986	1.044	1.009	1.039
Huaibei	1	1.014	0.993	1.006	1.014
Tongling	1.051	1.016	1.045	1.006	1.067
Anqing	0.969	0.99	0.981	0.988	0.96
Huangshan	0.991	1.025	1	0.991	1.016
Chuzhou	0.951	0.967	0.97	0.98	0.919
Fuyang	0.932	1.02	0.946	0.985	0.951
Suzhou	0.983	1.051	0.981	1.002	1.034
Lu'an	1.029	1.042	1.021	1.008	1.072
Bozhou	0.959	0.987	0.959	0.999	0.946
Chizhou	1	0.963	1.011	0.989	0.963
Xuancheng	0.989	0.923	0.997	0.992	0.914
Mean of Shanghai	0.941	1.151	1	0.941	1.083
Mean of Jiangsu	0.983	1.000	1.004	0.979	0.982
Mean of Zhejiang	0.958	1.025	0.988	0.970	0.982
Mean of Anhui	0.994	0.998	0.998	0.995	0.992
Mean	0.980	1.005	0.997	0.983	0.985

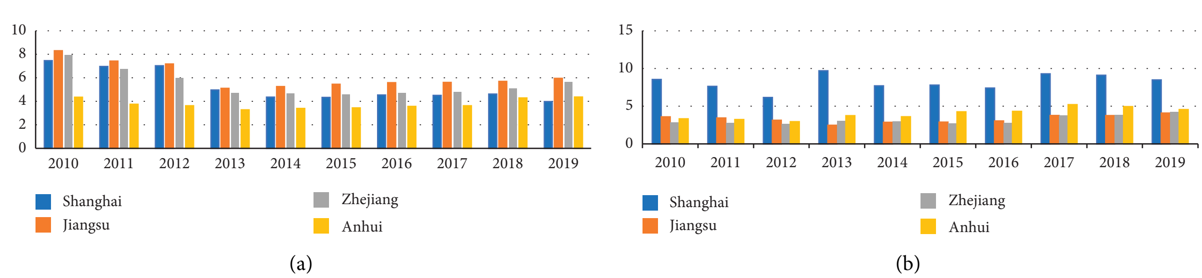
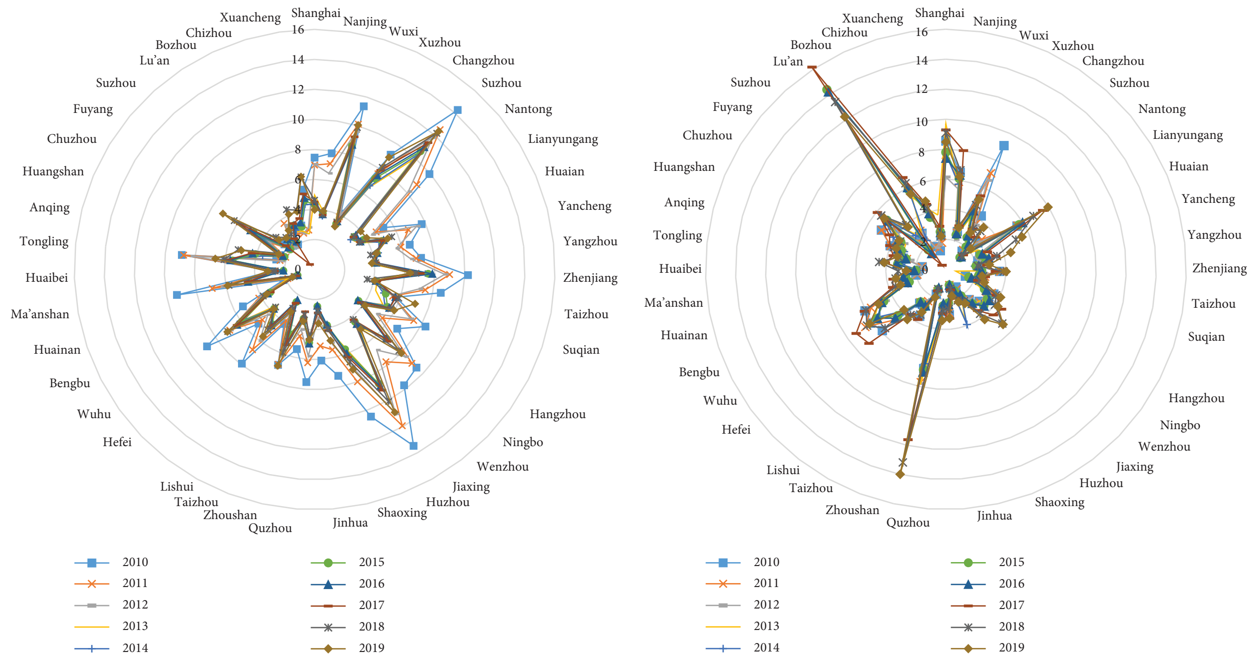


Figure 5: (a) The average agglomeration level of the manufacturing industry in 2010–2019 and (b) average agglomeration level of the logistics industry in 2010–2019.



(a) (b)

Figure 6: (a) The agglomeration level of the manufacturing industry and (b) agglomeration level of the logistics industry.

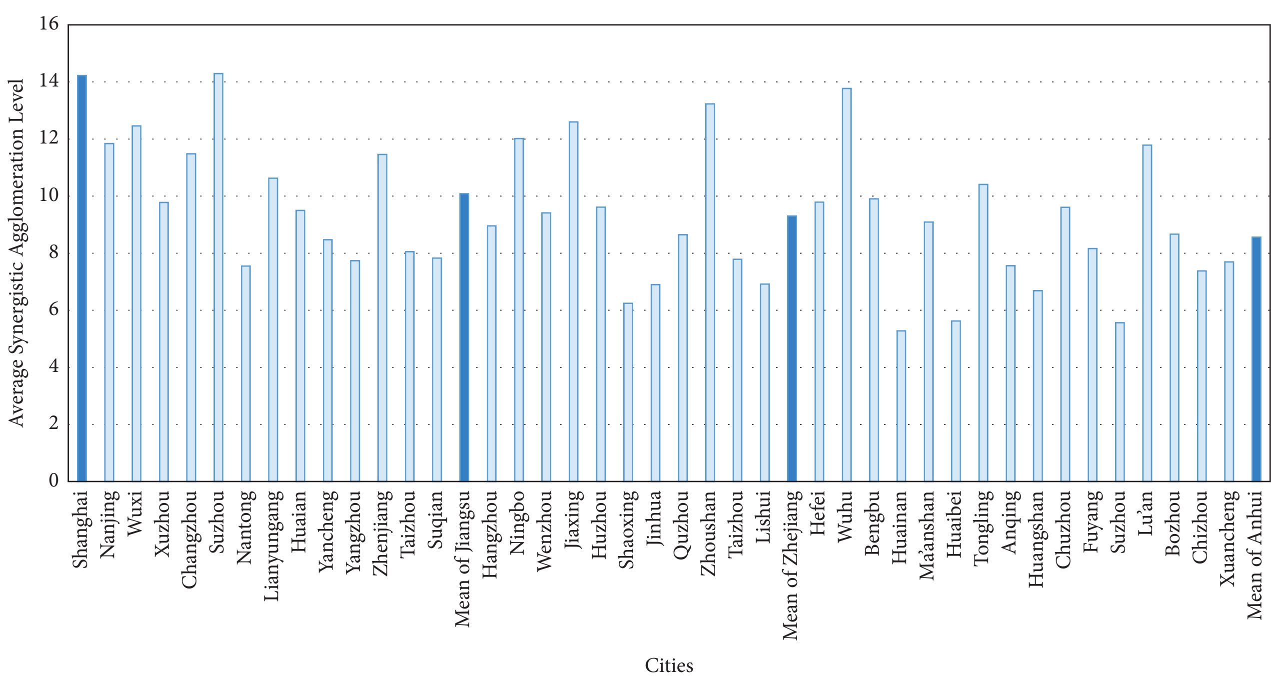


Figure 7: Mean of the synergistic agglomeration level of the two industries in 2010–2019.

negative but not significant effect on GEE. By comparing the calculation of the level of ISA in Figure 4, it can be found that the ISA level in Shanghai is relatively high, which is very likely to indicate that the level of synergistic agglomeration of the two industries in Shanghai has brought about "congestion effect." For Jiangsu and Zhejiang, the agglomeration of the manufacturing industry has a negative effect on GEE, while the agglomeration of the logistics industry and the synergistic agglomeration of the two industries have a positive effect on GEE, but these effects are not significant.

Overall, the impact of the synergistic agglomeration level of manufacturing and logistics industries on the four provinces and in the YRD region shows obvious regional heterogeneity. In a less developed province such as Anhui,

Table 7: Tobit regression results of the main influencing factors of GEE.

Terms	YRD region		Shanghai		Jiangsu		Zhejiang		Anhui	
	Co	Prob.	Co	Prob.	Co	Prob.	Co	Prob.	Co	Prob.
C	0.784	0.024	99.850	0.003	0.149	0.860	1.547	0.035	0.181	0.789
*In*GOV	0.045	0.127	−6.072	0.000	0.052	0.410	−0.046	0.417	0.107	0.067
SOCIAL	−0.001	0.507	−0.710	0.007	−0.011	0.023	0.002	0.759	−0.001	0.761
INSTRU	−0.008	0.006	−0.347	0.000	0.003	0.768	−0.004	0.642	−0.011	0.007
*In*EDU	0.005	0.812	1.867	0.000	0.009	0.853	−0.071	0.205	0.083	0.024
*In*FOREIGN	−0.032	0.087	3.743	0.000	0.034	0.576	0.013	0.718	−0.092	0.018
AGGL1	0.010	0.188	0.734	0.000	−0.005	0.674	−0.009	0.636	0.018	0.362
AGGL2	0.005	0.499	0.536	0.000	0.016	0.337	0.017	0.287	0.014	0.242
AGGLCO	0.016	0.002	−0.010	0.832	0.012	0.199	0.018	0.116	0.031	0.001

the improvement of the synergistic agglomeration level can still lead to green economy, whereas in a more developed region such as Shanghai, "congestion effect" is showing.

3.4.2. Influence of Other Influencing Factors. In the YRD region as a whole, the government's intervention in Shanghai and Zhejiang has not played the role of promoting the efficiency of green economy. Too much fiscal investment may lead to low efficiency of capital utilization, resulting in diminishing marginal returns and consequently restricting the development of green economy. In the YRD region in general and Jiangsu Province in particular, the fiscal support provided by the government has promoted the GEE, but the promotion effect is not obvious. In Anhui, government intervention is significantly related to GEE positively. Therefore, it can be inferred that the more developed the region, the less dependent it is on financial support and the higher the requirement for the rationality of financial input; on the contrary, for less developed regions, financial support is still one of the powerful means to promote green development.

The higher the level of urbanization, the higher the requirements for infrastructure construction, which may provide more facilitation to regional development. In general, the level of urbanization promotes the GEE in Zhejiang, but the promoting effect is not significant. However, in the whole YRD region and the other three provinces, the larger the urban population, the more pollution and waste discharge from production and household activities, which restrict the improvement of the GEE. In Shanghai and Jiangsu, this situation is more serious.

In Jiangsu, the increase in the proportion of the secondary industry promotes the improvement of regional GEE; however, in the whole YRD region and other three provinces, the higher the proportion of the output value of the secondary industry in the total output value, the greater the environmental pressure it will bring in the production process, and this situation is particularly serious in the whole YRD region, Shanghai, and Anhui but less serious in Zhejiang. This is most likely because the majority components of the secondary industry have not entered the stage of high-quality and high-tech development, and the increase of output value is accompanied by environmental pollution inhibiting GEE improvement; thus, adjustment of the industrial structure is imperative.

The education level of human resources has a facilitating effect on GEE in the YRD region and most of its provinces. The higher the level of education, the greater the potential of technological innovation and the possibility of promoting high-quality and green development of the industry. The boost is particularly evident in Shanghai, where high-end talents are gathered, and a stronger sense of green development is rooted in people's minds. This is also consistent with the reason why Shanghai has the highest GEE as stated in the previous analysis of the GEE result.

The influence of the level of opening to the outside world on the GEE shows regional heterogeneity. Among them, the level of opening to the outside world of Shanghai greatly promotes the improvement of the efficiency of green economy. As a city with the highest level of opening-up in China, Shanghai's dependence on foreign investment not only promotes its development but also promotes its green development. But in inland areas such as Anhui, the deepening of the degree of opening to the outside world increases the demand of domestic enterprises for export, which to a certain extent intensifies the consumption of resources and environmental pollution.

4. Conclusion and Discussion

4.1. Conclusion. Based on the panel data of 41 cities of the YRD region, the efficiency of urban green economy is measured using the superefficiency SBM model, the agglomeration level of the manufacturing and the logistics industries, as well as the synergistic agglomeration level of the two industries, is calculated using the location entropy method, and the Tobit regression model is used to analyse the influencing factors and influence mechanism of factors on the GEE. The conclusions of the research study can be given as follows.

First is static efficiency. The overall GEE of the YRD region is not ideal, and the ranking of the efficiency value is Shanghai > Jiangsu > Zhejiang > Anhui; the level of economic development and the ability of technological innovation promote the improvement of green efficiency; cities with beautiful natural environmental resources and adhering to the concept of green development have higher

GEE; resource-based cities are faced with the dilemma of resource depletion and the challenge on improving the GEE.

Second is dynamic efficiency. The GEE of the YRD region shows a U-shaped change, and technological progress is the most important factor affecting the regional GEE. Both scale efficiency and pure technological efficiency show fluctuating changes, which have no significant impact on the overall efficiency.

Third is the level of agglomeration and synergistic agglomeration. Cities with a high level of manufacturing agglomeration are mainly located in Jiangsu and Zhejiang, while those with a low level are mainly in Anhui. The agglomeration level of the logistics industry among cities is not uniform. In general, Shanghai has the highest ISA level of the two industries, followed by Jiangsu and Zhejiang, and Anhui has the lowest level. Many cities with a high level of synergistic agglomeration can play a good role in driving the synergistic agglomeration of their satellite towns and cities around them.

Finally, with the improvement of the synergistic agglomeration level of the manufacturing and logistics industries in the YRD region, the GEE tends to improve significantly. The effect of the ISA level of the two industries within the four provinces shows regional heterogeneity. The more developed the region, the less significant the effect of government financial support on GEE; the population gathering in cities may bring pollution, which is not conducive to the improvement of GEE; simply increasing the proportion of the secondary industry may not promote green development, and industrial structure transformation is imminent; high-quality talents can promote the improvement of GEE on the whole; developed coastal provinces with convenient transportation can strengthen the level of opening to the outside world, while less developed inland provinces may not pay too much attention to opening to the outside world to avoid waste of resources and too much development burden that may lead to low GEE.

By taking the collaborative agglomeration of the manufacturing and logistics industries as the starting point, this research enriches the perspective and content of the theoretical research on industrial collaborative agglomeration to promote the GEE. Also, this research takes the data of 41 cities in the YRD region as the sample to carry out the analysis and investigates the impact of the collaborative agglomeration of “two industries” on improving GEE from the level of Chinese prefecture-level cities, which is an effective supplement to the current relevant studies which mainly take provincial-level data as the empirical sample. By researching on the status quo of the synergistic agglomeration level of the manufacturing and logistics industries and GEE in the YRD region, exploring the influencing factors of GEE, analyzing the influencing mechanism of the two industries’ synergistic agglomeration on GEE, and investigating regional heterogeneity, this research provides a clear image of the synergistic agglomeration status of the two industries in the region, as well as the static and dynamic GEE and its influencing factors, which is of practical significance in finding the problems in the process of industry transformation and regional green development.

4.2. Discussion. Based on the conclusions mentioned previously, there are two parts worth thinking about. First is the way of optimizing the green transformation of industrial structure. Second is the improvement and direction setting of the government policy.

4.2.1. The Way of Optimizing the Green Transformation of Industrial Structure. Optimizing the green transformation of industrial structure is necessary. A reasonable industrial structure can promote the green development of the YRD region. However, in the whole YRD region and three of its provinces, the higher the proportion of the secondary industry, the more restricted the green development, and for the other provinces, the facilitation effect is not obvious. In view of the situation, modern upgrading is not only relevant to the traditional strengthening of the secondary and tertiary industries but also imperative to the cultivation of the emerging industries. On the one hand, it is undeniable that the rapid development of the YRD region in the past was inseparable from the dependence on the secondary industry. Although manufacturing has brought about environmental troubles, it has also accumulated resources and laid a foundation for the development of the region; on the other hand, it can be found from the empirical analysis that it is not advisable to increase the proportion of the secondary industry at the expense of the environment. In the face of the gradual depletion of resources, priority should be given to the development of advanced and technology-intensive industries, and industrial transition and transformation should follow the criteria of environmental friendliness, ecological green, and high quality. Resource and factor advantages created by the industrial synergistic agglomeration should be fully utilized to leverage the role of synergistic industrial agglomeration in urban green development. From the perspective of the synergistic agglomeration of manufacturing and logistics industries, the synergistic alignment and integrated development of the two are good ways to optimize and upgrade industrial structure transformation. Logistics, as a separate component of the traditional manufacturing industry, can fully create the value spillover effect through provincial cooperation and regional cooperation of the industry in setting up a scientific, systematic, advanced logistics network and value chain.

4.2.2. Policy Suggestions. Local governments should not only strengthen the indoctrination of the green development concept in society and among enterprises and use natural resources sustainably, but they should also realize horizontal and vertical coordination of intergovernmental cooperation in policy and build a guarantee mechanism for the interaction of industry, technology, and talent. Specific policy recommendations are as follows:

(1) We strengthen horizontal intergovernmental cooperation, adjust the degree of industrial collaboration, avoid congestion effect, and optimize resource allocation. In Shanghai, empirical results show that the synergistic agglomeration of the two industries may

have evidenced the trend of "congestion effect;" thus, it is important to grasp the degree and orientation of industry synergistic agglomeration. In the whole YRD region and three other provinces, synergistic agglomeration of the two industries gradually play a great role in promoting the green development of cities. Therefore, the geographical advantages of the YRD region can be used to strengthen cooperation among provinces and cities. To be more specific, on the one hand, provinces with "congestion effect" can appropriately transfer the manufacturing and logistics enterprises to the industrial parks in neighbouring cities. On the other hand, the awareness of cooperation among provinces and cities should also be raised. High-quality development also requires high-quality synergistic agglomeration, which is not only the traditional agglomeration of labour and geographical location but also includes the agglomeration of technology, innovation, resources, advanced equipment, and high-end talents. Provinces and cities that develop faster can share high-end talents, technology, and information resources with those that develop slower and should leverage their leading role, focusing on the present situation of the surrounding cities, to make full use of potential cooperation space and resources so that more proper allocation of resources in the whole YRD region can be achieved, and in this way, bottlenecks can be alleviated in areas impacted by the "congestion effect," and at the same time, the utilization efficiency of resources can be improved, resource waste can be reduced, cost saving can be realized, and green development can be promoted.

(2) We adjust the vertical intergovernmental relationship at all levels, realign government support, and realize the balance between competition and cooperation among local governments. It can be found from the empirical research that the synergistic agglomeration levels of manufacturing and logistics industries are different, and the influence mechanism of each influencing factor also has regional heterogeneity. In deciding how to optimize the allocation of local resources, how to reform the economic system, and how to upgrade the industrial structure, local governments play the "key actors" role [60]. With the deepening of the reform process of China, resources such as land, labour, energy, and natural resources are increasingly scarce, the government tends to use more fiscal resources that are more controllable to serve the local people and the market. Fiscal support is one of the good instruments for promoting development, but in the absence of competitive pressure and a clearer orientation of funding, pure fiscal support can lead to a weak sense of efficiency and is therefore detrimental to green and high-quality development. Specifically, the vertical allocation of fiscal revenue may lead to the lack of efficiency and competition awareness of local governments, resulting in low efficiency in the use of funds. Therefore, optimizing the fiscal relationship between vertical governments and maximizing the role of fiscal funding can stimulate local governments to increase investment in transformation. Adjusting vertical intergovernmental relations, urging local governments to improve their financial self-sufficiency rate, and enhancing their awareness of efficiency are conducive to governments when seeking a balance between competition and cooperation and when exploring more favorable models for high-quality and green development.

(3) We build a comprehensive mechanism for personnel training to promote technological progress and green development. The accumulation of talent resources usually includes introduction, cultivation, and safeguarding a talent pool. The establishment of a comprehensive talent management mechanism is conducive to providing an all-round good development environment for talent training, service, incentivization, and secure provision.

4.2.3. Further Discussion. In this research, GEE and its influencing factors, especially the influence of the manufacturing and logistics industries synergistic agglomeration in it on the city scale, are studied, which has great reference significance for adjusting industrial structure and government regulation. But attention should also be paid to the following deficiencies and new discussions can be raised: first, as time goes by, data sources will become richer, and the efficiency measurement indicators and influencing factor indicators selected in this research can be updated accordingly. Secondly, this research explores the influencing factors of urban GEE, but the influence may be nonlinear or there may be mediating variables, which can be further discussed in future research.

Data Availability

The data are collected from China Urban Statistical Yearbook, China Energy Statistical Yearbook, China Industrial Statistical Yearbook, and China Environment Statistical Yearbook. All data used to support the findings in this manuscript can be made available upon request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was financially supported by the Key Humanities and Social Science Research Project of Universities in Anhui Province (SK2021A0288) and Science and Technology Activities Project for Returnees from Overseas Study in Anhui Province (S012014016).

References

[1] D. W. Pearce, *Blueprint for a Green Economy: A Report*, Earthscan Publications Ltd, London, UK, 1989.
[2] W. J. Meng, X. L. Zhang, and Q. S. Xing, "Research on the influence of industrial Co-agglomeration on urban green economy development: based on the Yangtze River Delta urban agglomeration," *Ecological Economy*, vol. 38, no. 2, pp. 67–74, 2022.
[3] F. Yan, "Spatial correlation and influencing factors of logistics industry and manufacturing industry Co-agglomeration," *Statistics & Decisions*, vol. 37, no. 7, pp. 113–117, 2021.
[4] Q. Wei, "Empirical study of linkage evolvement between manufacturing and logistics industry," *Journal of Zhongnan University of Economics and Law*, vol. 1, pp. 115–119, 2011.
[5] H. S. Ma, F. Zhao, and Y. S. Yan, "Research on the formation and evolution conditions of manufacturing and logistics synergistic agglomeration," *Journal of Highway Communication Technology*, vol. 39, no. 6, pp. 169–176, 2022.
[6] Y. D. Zhan, G. H. Han, and M. Dong, "Study on cooperative mechanism between production services and manufacturing," *Journal of Harbin University of Commerce (Natural Science Edition)*, vol. 28, no. 1, pp. 118–122, 2012.
[7] F. Zhao and D. Chen, "Industry relevancy between producer services and manufacturing in east asia," *World Economy Study*, vol. 7, pp. 73–80, 2012.
[8] J. B. Lu, "Coordination effect of producer service based on manufacturing agglomeration," *Chinese Journal of Management*, vol. 11, no. 3, pp. 396–401, 2014.
[9] W. C. Qi, "Research on the mechanism and mode of the linkage development of manufacturing and logistics industry," *Technology Innovation and Application*, vol. 14, p. 259, 2015.
[10] L. Zhou, "Mechanism and mode of manufacture and logistics integration," *Logistics Technology*, vol. 5, pp. 102–105, 2015.
[11] H. Zhu, G. G. Zhou, and G. Y. Ren, "Research on spatial Co-agglomeration between manufacturing industry and logistics industry: a case study of six provinces in Central China," *Economic Geography*, vol. 11, pp. 117–124, 2015.
[12] H. X. Tang, W. Y. Xia, and Y. Huang, "Identification of influencing factors and breakthrough path of collaborative agglomeration of manufacturing industry and logistics industry in new land-sea corridor in western China," *China Soft Science*, vol. 8, pp. 131–139, 2022.
[13] X. Y. Jin, "City size, industrial linkage and Co-agglomeration - based on the industrial linkage and spatial interaction between manufactures and producer services," *Industrial Economic Review*, vol. 6, pp. 35–46, 2015.
[14] H. Zhang and S. L. Wu, "Influence of Co-agglomeration of logistics industry and manufacturing industry on resident consumption expansion:an empirical analysis based on the dubin model of dynamic space," *Consumer Economics*, vol. 38, no. 2, pp. 41–56, 2022.
[15] L. Deng, "The empirical analysis on the linkage development of the manufacturing and logistics industry in China," *China Business and Market*, vol. 7, pp. 29–36, 2013.
[16] Z. Z. Wang, "Self-organization evolutionary dynamic model of manufacturing industry and logistics industry," *Statistics & Decisions*, vol. 17, pp. 36–39, 2014.
[17] X. Q. Jin, "Interactive development between manufacturing industry and logistics industry in the Yangtze River economy belt," *Journal of Nantong University (Social Sciences Edition)*, vol. 1, pp. 16–22, 2017.
[18] Z. J. Jiang and Q. L. Dong, "The study on competing relationship of interactive development between manufacturing and logistics industry - based on integrated field," *Technoeconomics & Management Research*, vol. 8, pp. 13–16, 2015.
[19] B. Wang, Z. Yang, Y. Y. Chen, J. J. Li, and J. Chen, "Green economy efficiency influence mechanism," *Shanghai Economic Research*, vol. 6, pp. 62–77, 2022.
[20] X. C. Cai and H. X. Xu, "Economic policy uncertainty and green economic efficiency," *Journal of Nanjing University of Finance and Economics*, vol. 1, pp. 54–63, 2022.
[21] D. F. Cai, Q. J. Dong, Y. Zhu, and Y. S. Lian, "Industrial agglomeration, population structure and green economy efficiency," *Statistics & Decisions*, vol. 38, no. 7, pp. 112–116, 2022.
[22] Y. Q. Zhou and F. Gu, "Research on the impact of land resource mismatch on the efficiency of urban green economy," *Academic Exploration*, vol. 2, pp. 104–115, 2022.
[23] X. X. Lin, "The influence of economic agglomeration on green economy efficiency," *Finance and Economics*, vol. 5, pp. 89–102, 2021.
[24] P. D. Zhang and X. W. Tu, "The bilateral impact of manufacturing agglomeration on green economy efficiency," *Economic Theory and Business Management*, vol. 41, no. 11, pp. 35–53, 2021.
[25] J. P. Li, L. Q. Xu, F. C. Tang, and D. Yao, "The impact of public transport facility scale on green economy efficiency," *Journal of Systems Management*, vol. 30, no. 6, pp. 1053–1066, 2021.
[26] Z. Zhang, X. S. Li, and C. Wang, "Labor price distortion and the loss of green economic efficiency," *Journal of Yunnan University of Finance and Economics*, vol. 36, no. 4, pp. 51–63, 2020.
[27] B. Q. Lin and R. P. Tan, "Economic agglomeration and green economy efficiency in China," *Economic Research Journal*, vol. 54, no. 2, pp. 119–132, 2019.
[28] L. Y. Zhu, T. Li, L. Y. Ma, and G. Z. Sun, "Cities' green economy efficiency evaluation under haze constraint: an empirical study of metropolitan area of jing-jin-ji, Yangtze River Delta and pearl River Delta," *Science and Technology Management Research*, vol. 38, no. 22, pp. 58–63, 2018.
[29] L. Yang and X. Z. Hu, "Analysis on regional difference and convergence of the efficiency of China's green economy based on DEA," *Economist*, vol. 2, pp. 46–54, 2010.
[30] H. L. Wang, X. Y. Lian, and D. M. Lin, "Effects of green technological innovation efficiency on regional green growth performance: an empirical analysis," *Science and Management of S.& T.*vol. 37, no. 6, pp. 80–87, 2016.
[31] Z. J. Feng, C. J. Yang, and X. Kang, "Green innovation and green growth of industrial enterprises:an empirical study based on guangdong," *S & T Management Research*, vol. 37, no. 20, pp. 230–235, 2017.
[32] Z. Li and S. Yang, "Fiscal Decentralization,Government innovation preferences and regional innovation efficiency," *Management World*, vol. 34, no. 12, pp. 29–42, 2018.
[33] L. D. Zhao, L. Zhang, R. J. Li, and M. Y. Yang, "Energy Endowments,Human capital and China's economic performance under the dual regulation of the resources and the environment," *Modern Economic Science*, vol. 35, no. 4, pp. 74–84, 2013.
[34] Y. M. Li and M. Hua, "Green efficiency of Chinese cities: measurement and influencing factors," *Urban and Environmental Studies*, vol. 2, pp. 36–52, 2014.
[35] Y. B. Liu, H. X. Yuan, and W. Zhe, "Dynamic panel data modeling of the effects of cultural industry clusters on green

economic efficiency," *Resources Science*, vol. 39, no. 4, pp. 747–755, 2017.

[36] J. L. Sun and P. Y. Zhu, "Evaluation of 'belt and road' provinces' green economic efficiency and analysis of influencing factors based on SBM-malmquist-tobit," *S & T Management Research*, vol. 39, no. 4, pp. 230–237, 2019.

[37] H. N. Zhang, Z. R. Geng, R. S. Yin, and W. Zhang, "Regional differences and convergence tendency of green development competitiveness in China," *Journal of Cleaner Production*, vol. 254, Article ID 119922, 2020.

[38] H. L. Jiang and P. C. Jiang, "Research on the impact of digital finance on the efficiency of urban green economy," *Soft Science*, vol. 36, no. 4, pp. 37–43, 2022.

[39] F. H. Zeng and S. Y. Xiao, "The impact of digital finance on the efficiency of urban green economy," *Statistics & Decisions*, vol. 38, no. 15, pp. 144–148, 2022.

[40] N. Guan, X. Y. He, and B. Y. Li, "Research on the impact of digital service economy on green economy efficiency in beijing-tianjin-hebei region," *Macroeconomic Study*, vol. 7, pp. 105–119, 2022.

[41] S. Roumei and F. Deng, "The nonlinear effect of human capital agglomeration on green economy efficiency," *Social Scientist*, vol. 8, pp. 96–102, 2020.

[42] N. Zhang and A. J. Guo, "Study on the impact of service agglomeration on green economic efficiency of cities in the yellow river basin," *City Problems*, vol. 86, no. 4, pp. 35–44, 2022.

[43] Y. J. Ren, Y. X. Qi, and D. Liang, "The effect of producer services agglomeration on the efficiency of urban green economy," *Statistics & Decisions*, vol. 19, pp. 120–123, 2022.

[44] X. F. Wu and Y. D. Yang, "Have Co-agglomeration of producer services and manufacturing promote urbanization level," *Finance and Economics*, vol. 11, pp. 79–90, 2016.

[45] J. T. Zhang, Y. Zhu, and B. You, "Research on the influence of industrial collaborative agglomeration on the green development of urban economy," *Urban Problems*, vol. 2, pp. 66–74, 2021.

[46] Z. H. Wu, "The service industry, collaborative agglomeration of strategic emerging industries and high-quality economic growth - empirical analysis based on provincial panel data from 2005 to 2018," *Journal of Henan Normal University (Philosophy and Social Sciences Edition, Bimonthly)*, vol. 4, pp. 44–50, 2020.

[47] Q. X. Zhao, C. X. Xia, and J. J. Shi, "Sci-tech talents agglomeration, industry agglomeration and regional innovation capability: empirical analysis based on jing-jin-ji region, Yangtze River Delta and pearl River Delta," *S & T Management Research*, vol. 24, pp. 54–62, 2019.

[48] M. Fang, S. G. Yang, J. J. Zhou, and Y. L. Lei, "The innovative development path of industry agglomeration in Yangtze River economic belt under the background of high-quality development," *China Soft Science*, vol. 5, pp. 137–150, 2019.

[49] Y. Ma, Y. H. Qiu, and X. Y. Wang, "Research on the effect of high-tech industry agglomeration and innovation on high-quality economic development - regression model based on panel smoothing transformation," *Journal of Industrial Technological Economics*, vol. 2, pp. 13–20, 2020.

[50] X. M. Feng, R. J. Zhang, and P. Y. Yang, "Has synergistic industrial agglomeration promoted green development? Spatial econometric analysis based on 285 cities," *Journal of Finance and Economics*, vol. 3, pp. 71–81, 2022.

[51] M. Liu, "The influence of collaborative agglomeration of logistics industry and manufacturing industry on high-quality economic development--the empirical research on 283 cities at the prefecture level and above," *China Business and Market*, vol. 35, no. 9, pp. 22–31, 2021.

[52] F. Yan and T. S. Wang, "Professional agglomeration and cooperative agglomeration of logistics industry and manufacturing industry and regional economic growth," *Enterprise Economy*, vol. 40, no. 4, pp. 88–97, 2021.

[53] A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the efficiency of decision making units," *European Journal of Operational Research*, vol. 3, no. 4, pp. 339–444, 1979.

[54] K. Tone, "A slacks-based measure of super-efficiency in data envelopment analysis," *European Journal of Operational Research*, vol. 143, no. 1, pp. 32–41, 2002.

[55] J. J. Chen and J. J. Chen, "The research on the Co-location between producer services and manufacturing: the empirical analyses based on the 69 cities and regions in Zhejiang province," *China Industrial Economics*, vol. 6, pp. 141–150, 2011.

[56] J. Tobin, "Estimation of relationships for limited dependent variables," *Econometrica*, vol. 26, no. 1, pp. 24–36, 1958.

[57] J. Zhang, G. Y. Wu, and J. P. Zhang, "The estimation of China's provincial capital stock: 1952-2000," *Economic Research Journal*, vol. 10, pp. 35–44, 2004.

[58] Z. J. Wu and N. J. Wu, "Research on the measurement, decomposition and influencing factors of green economic efficiency in the Yangtze River economic belt: based on super-efficiency SBM-ML-tobit model," *Urban Problems*, vol. 1, pp. 52–62, 2021.

[59] L. L. Ding, L. Zhu, and G. S. He, "Measurement and influencing factors of green total factor productivity of marine economy in China," *Forum on Science and Technology in China*, vol. 2, pp. 72–78, 2015.

[60] X. Gao, "Government efficiency: the big problem in China's public management," *Public Administration and Policy Review*, vol. 1, pp. 55–62, 2020.